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Carderock Division
West Bethesda, MD 20817-5700

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Model Test Report of a 50,000 Ton Heavy Lift Ship as a Seabased Intermediate Transfer Station

By

Dan Sheahan

Richard McIlwaine

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14. ABSTRACT
A Center for Innovation in Ship Design model test was conducted to investigate the use of a Heavy Lift Ship as a Sea Base Intermediate Transfer Station (ITS). The ITS provides a platform whereby stores and equipment can be transferred from a large Ro/Ro vessel onto smaller transport vessels. This report describes the model tests conducted and the results obtained while analyzing the suitability of using a Heavy Lift Ship in this role. The testing showed a 30%-60% reduction in wave height within the lee of the HLS, depending on the sea state. No deck wash from the windward side was observed, however, testing in sea state 6 showed some limited 'scooping' of water by the deck edge on the lee-side of the HLS due to the increase in roll motion in higher sea states. Based on these results, it is suggested that the ITS configuration enables unlimited transfer operations in sea state 3 and possible operations in sea state 4.

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Abstract

The Intermediate Transfer Station (ITS) is the concept of using a Heavy Lift Ship (HLS) moored perpendicularly to the stern of a Ro/Ro ship such as a Large Medium Speed Ro/Ro (LMSR) within a Sea Base environment. The deck of the HLS can then be used as a transfer station for the off-load of personnel, material and wheeled and tracked vehicles from the Ro/Ro ship or other large ships on to lighter Landing Craft Utility (LCU) and Landing Craft Air Cushion (LCAC) vehicles.

The ITS configuration requires the Ro/Ro vessel to be aligned head to the dominant sea direction so that its primary response is pitch. By contrast, the HLS will be perpendicular to the Ro/Ro (i.e. beam on to the incident waves) to create a lee such that its primary response is roll. The combination of pitch and roll minimizes torsional load on the stern ramp of the Ro/Ro vessel.

Listing the HLS by approximately 2º provides a 'seawall' to the incident waves and helps to minimize the drop down angle of the stern ramp, and hence the resulting inclination for the vehicles to negotiate is reduced. The low-side (on the leeward side) provides a simple interface for the lighters – LCAC's simply board the deck to load and unload (which requires going off-cushion) and LCUs simply drop their bow ramp.

To maintain a constant separation between the Ro/Ro ship and the HLS, it is envisaged the Ro/Ro ship would maintain a slight forward speed. The HLS should use its thrusters to 'pull' in the appropriate direction, thereby maintaining the original location of the configuration.

The main objectives of the ITS testing was to quantify the lee of the HLS, determine the likelihood of deck wash and ramp torsion, and the corresponding conditions most likely to cause it, and to obtain an estimate of the thruster forces that would be required at full

scale to keep the required configuration. A number of capacitance wave probes and a sonic wave probe were employed to study the motion of the waves, and a series of load cells were used to study the forces required in keeping the models in position.

There were three models produced for testing, each at a scale of 1:158. 3D models to support construction were produced in Rhino using offset data for each ship concerned. Testing was conducted in a 140 ft tank at NSWCCD, following the design and installation of a wavemaker. The configuration used involved the sonic wave probe being placed at the front of the configuration to measure and record the incident waves, then having the LMSR head-on to the direction of the waves. At the stern of the LMSR the HLS is connected, but perpendicular to the direction of the waves, and to the LMSR. Then finally, behind the HLS, the capacitance probes were placed in the lee of the ship to study the resultant waves.

The main conclusion is a 30%-60% reduction in wave height within the lee of the HLS, depending on the sea state. No deck wash from the windward side was observed, however, testing in sea state 6 showed some limited 'scooping' of water by the deck edge on the lee-side of the HLS, due to the increase in roll motion in higher sea states. Based on the results here it is suggested that the ITS configuration enables unlimited transfer operations in sea state 3, and possible operations in sea state 4.

Acknowledgements

This project would not have developed as it did without the assistance of numerous people at NSWCCD, mainly from within Code 50 and the model shop. The team would like to thank, in particular, Dr. Colen Kennell and Mr. Mark Selfridge (UK MoD Exchange Officer) for providing invaluable insight and advice in marine engineering and naval architecture throughout the project. Our thanks is also extended to Mr. Matthew Powell, who provided components and assisted generally in the data acquisition process, and also to Mr. John Hamilton for assisting with and implementing the wave maker.

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Introduction

Sea Base Concept

The recent conflicts in Iraq and Afghanistan have highlighted the dependence of the US military on other nations to conduct large-scale operations sizeable distances from the Continental United States (CONUS). The US relied heavily on third party host nations to provide air bases, ports, command and control centres and other facilities in conducting offensive operations, and suffered a loss in capability when Turkey, a NATO member, refused to allow any significant level of access to coalition forces during Operation 'Iraqi Freedom'. This highlights that, especially since the American response to the terrorist attacks of 11th September 2001, political and religious considerations now often outweigh military ties.

To counter this reliance on third party host countries the idea of a Sea Base has been developed. It incorporates moving away from large-scale amphibious assaults and moving towards light, rapidly deployable, highly manoeuvrable forces capable of beaching on to the coast and transporting inland to their objective. The Sea Base would be responsible for providing both a staging area and logistical support to the troops, up to the size of a Marine Expeditionary Battalion (MEB).

Some early concepts of the Sea Base focused on large mobile offshore bases that could be capable of accommodating airlift-sized aircraft such as the C-130J. These have been expanded to include facilities for accepting, sorting and forwarding personnel and materiel, along with the capability to retrieve this personnel and material, and to provide medical facilities. The Sea Base concept has since moved further towards a collection of dispersed vessels that can provide individual capabilities such as those mentioned above, as well as defence assets, Command & Control, Communications, Computers and Intelligence (C4I) nodes, and Intelligence Surveillance Reconnaissance (ISR) network nodes in the combination desired for any particular mission.

A future Sea Base is likely to be positioned at least 25nm from shore, from which LCACs and Expeditionary Fighting Vehicles (EFVs) can reach the beach in under an hour. Distances up to 250nm have been stated (the range of MV22). If the situation allows it, the Sea Base may be able to move closer to shore to allow the slower LCU landing craft, which can transport heavier equipment, to be offloaded in a reasonable length of time, as well as being close enough to pump water and fuel across the beach.

A nominal future Sea Base could consist of a Carrier Strike Group (CSG) and a Maritime Positioning Group (MPG), both supported by a Combat Logistics Force and an Expeditionary Strike Group (ESG).

Intermediate Transfer Station Description

The Intermediate Transfer Station (ITS) concept utilizes a Heavy Lift Ship to transfer troops and equipment from a Large Medium Speed Ro/Ro (LMSR) ship onto individual transports such as the Landing Craft Utilities (LCU) 2000 and the Landing Craft Air Cushion (LCAC). These can then be used to transport the equipment from the Sea Base to the landing area.

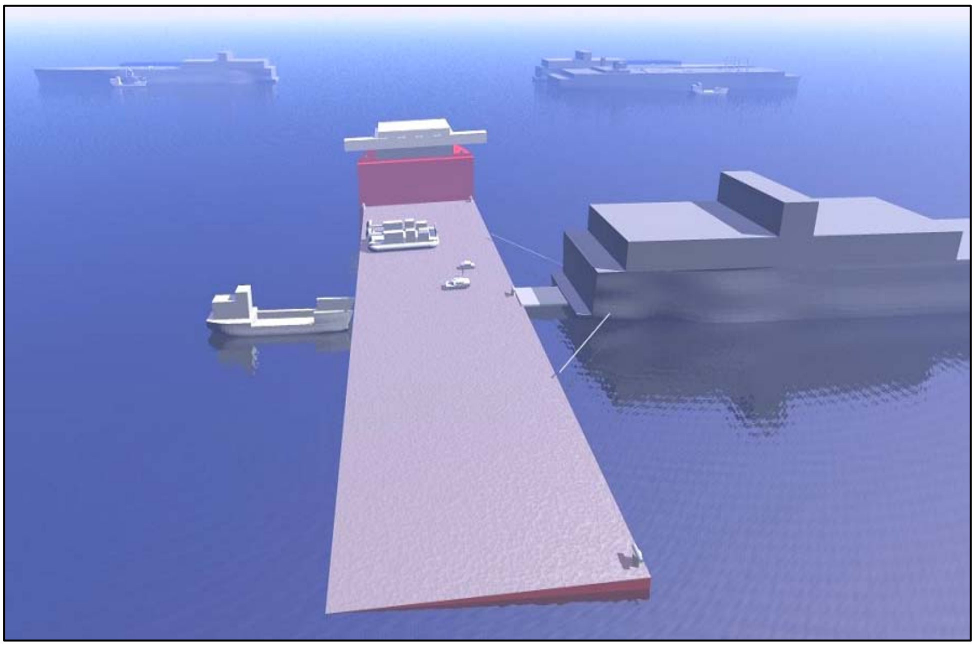

Figure 1 - ITS Configuration

Figure 1 shows equipment being transferred from a LMSR to a Heavy Lift Ship (HLS) using the stern ramp. Equipment such as wheeled and tracked vehicles, along with supplies, can then be loaded onto the LCAC whilst it is on the deck of the HLS, or by simply driving up the ramp of the LCU.

At present, vehicle transfer operations at sea are limited to Sea State 2 and below. It is intended that the HLS in the ITS configuration will be heeled slightly, providing a lee on the loading side of the ship. The objective in creating this lee is to enable operations to take place in stronger seas than Sea State 2. The heeling of the ship will also allow for LCACs to board the HLS and to come off cushion, and will provide easier access for the LCUs to moor up against the HLS.

Objectives

The objective of the ITS testing is to:

i. quantify the lee
ii. observe any deck wash from the windward side and identify causing conditions.
iii. observe any torsion on the ramp and identify causing conditions.
iv. determine order of magnitude of thruster forces.
v. observe relative ship motions.

Model Construction

Three models were constructed for the testing. All three models were built to a 1:158 scale and designed using the 3D drawing package Rhino. The LMSR and HLS were made out of wood in the workshop and the LCU was made using stereolithography.

LMSR and HLS

The hull of the LMSR and the HLS were both modeled using Rhino. The models were then passed to the workshop, enabling the machines to be programmed to produce the hulls. The wood used to make the two models was pine, and the superstructures were made out of foam and then secured on top of a plexiglas deck. The models were then ballasted correctly to provide the same mass properties as that of the full-scale ship.

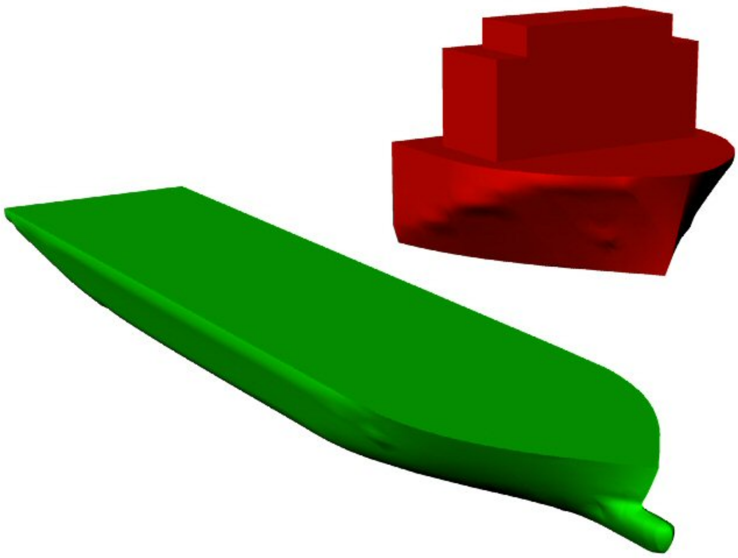

Figure 2 - HLS Rhino Model

Each model was then painted yellow above the waterline and black below it, with the deck of the HLS having a checked pattern to aid visibility of any deck wash during testing.

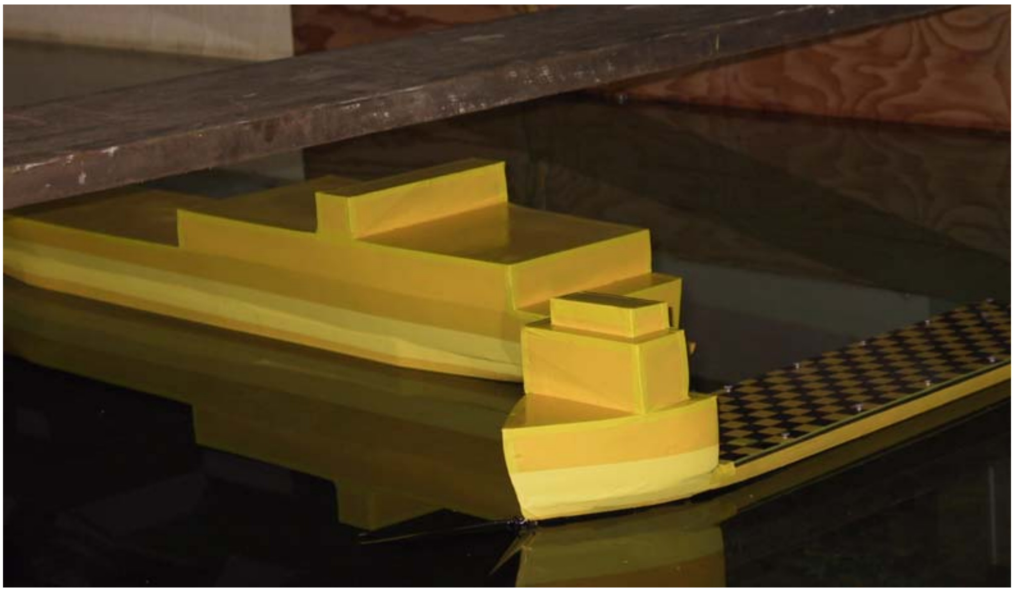

Figure 3 - Completed LMSR and HLS Models

LCU

The LCU was also designed using Rhino and sent to the workshop, but was produced using stereolithography, due to the costs associated with constructing a wooden model. The model was painted black and yellow.

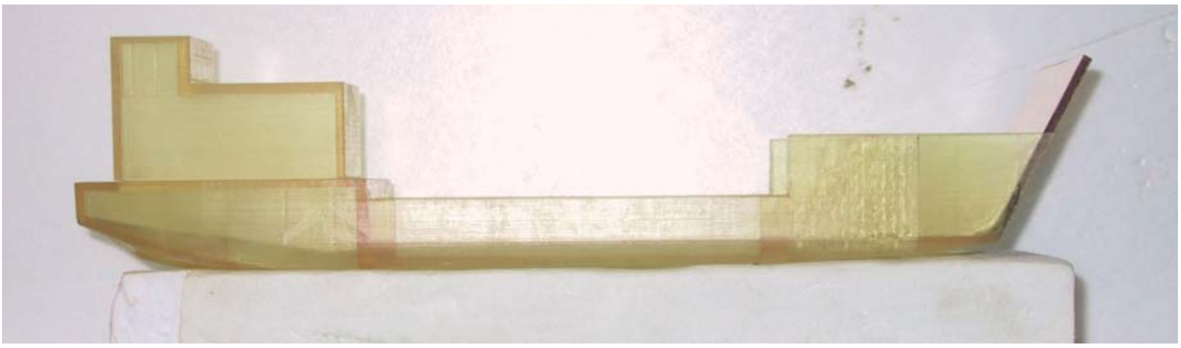

Figure 4 - LCU Model (unpainted)

Ballasting

The models was ballasted so they had the same properties as those of the ships. This entailed adding ballast weights to the models to shift their centre of gravity and to ensure they had the same displacement as the ships.

The HLS was heeled over by 6° so that the leeward deck was in contact with the surface of the water. The angle of 6° was determined by the width of the deck and is therefore specific to this HLS.

Testing Configuration

The Models

The general layout used in testing is shown in Figure 2. The wave direction is from left to right, with a sonic probe located at the front of the configuration. The LMSR and the HLS were moored using bungee cords, and the capacitance wave probes were placed within the lee of the HLS as shown.

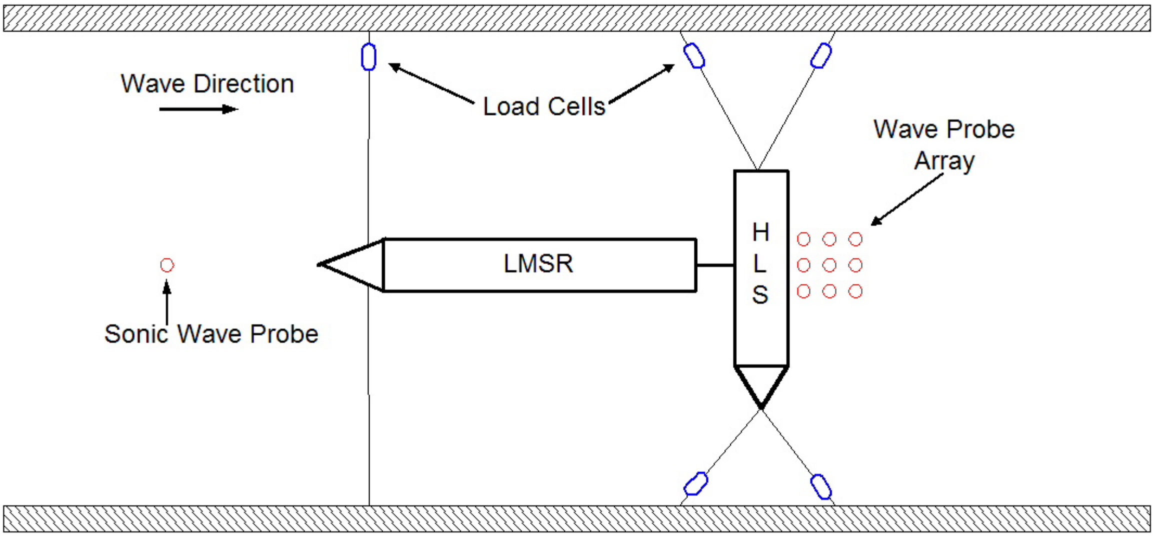

Figure 5 - Layout

The bungee cords were attached to the LMSR using eyelets positioned where the bow thrusters are located on the actual ship. The eyelets were located along the center of gravity of the HLS. The mooring was used to ensure that the models maintained their relative positions during the course of the testing. The alternative mooring configuration shown in Figure 6 was used to see if there are significant differences in the results gathered due to the way the models are constrained.

Wave Height

The wave heights chosen for testing were to reflect sea state 2 through sea state 7. The table below indicates the significant wave height in each sea state, and how that translates once the scaling factor of 1:158 has been incorporated.

Sea State	Range (ft)	Significant Wave Height (ft)	Scaled Wave Height (in)
2	0.3-1.6	1	0.076
3	1.6-4.1	2.9	0.22
4	4.1-8.2	6.2	0.471
5	8.2-13.1	10.7	0.813
6	13.1-19.7	16.4	1.246
7	19.7-29.5	24.6	1.868

The scaled seas used were based on sea spectra for Northern North Atlantic, and the Pacific Ocean (obtained from PNA – References, Section 0) to establish the significant wave height for each sea state. Sea states are, however, a function of modal period also, and so it was necessary to identify the most probable modal period for each sea state. The sensitivity to wave height was addressed by testing in sea states 2 through 7, and the sensitivity to modal period was addressed by testing at 3 different modal periods within each sea state, i.e. the most probable, and then +/– 10% from the most probable value.

Once the modal periods were chosen they were scaled down to model size by multiplying by 1 over the square root of the scale factor:

$$T_m = \frac{T_a}{\sqrt{S.F.}}$$

Where:
T_m - is the modal period for the model;
T_a - is the actual modal period;
S.F. - is the scaling factor.

Windward Side Freeboard

The freeboard on the windward side of the heavy lift ship is dictated by the expected sea state (i.e. the expected wave height) in which operations are planned. The heavy lift ship model used during testing reflected an existing heavy lift ship. The beam of the ship and the required freeboard dictated the list (deck slope) required in order to have the leeside deck edge of the ship at the water level. The larger the ship beam the smaller the list required, hence larger beamed heavy lift ships are more attractive.

The tests performed in sea state 2 through sea state 4 required that the HLS model be heeled to an angle of 5.6º, due to the relatively narrow beam. From sea state 5 and above, the increase in maximum wave height required an increase in freeboard, and so it was necessary for the HLS to be heeled to an angle of 6.4º.

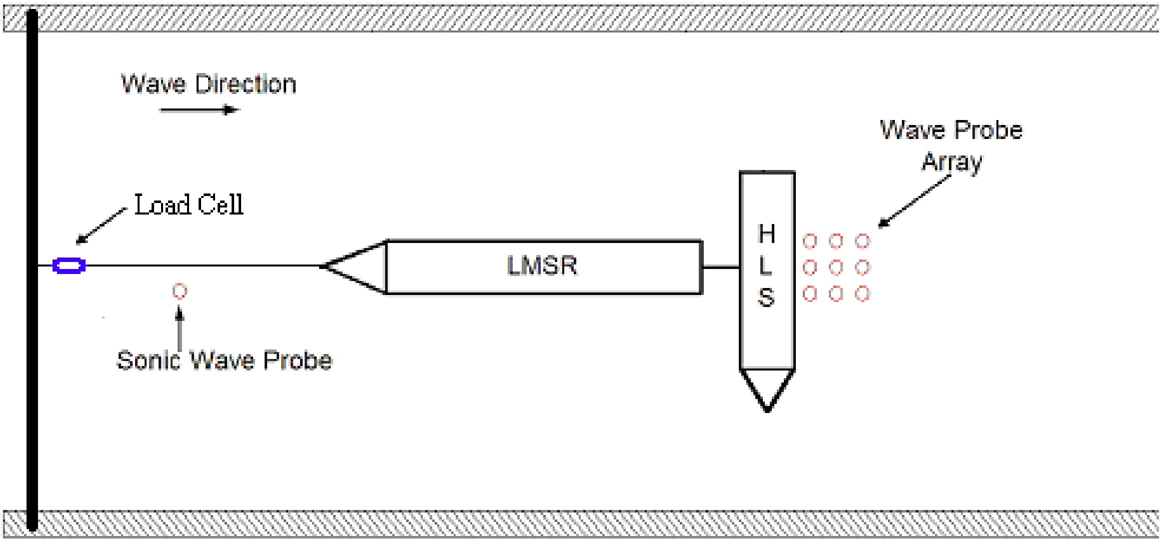

Figure 6 - Alternative Mooring Configuration

The Wavemaker

A vital part in establishing the response of the ITS configuration was the ability to generate irregular seas accurately in terms of wave height and modal period. A simple wavemaker consisting of a flat plate moved by two actuators was used to generate the waves. Varying the supplied voltage to the actuators controlled the amplitudes of the waves.

The digital signal sent from the computer is converted into an analog signal using a Data Acquisition Card (DAQ Card). From this point the analog signal is sent to the power controller, where it is converted back to a digital signal to generate the voltages required in running the actuators.

The actuators each have a pitch of five inches, and are capable of advancing to a maximum of two and a half inches. Each actuator has three magnets that connect to circuits at three points in the shaft. The magnets indicate full extension, full retraction, and the midway point between the two. The middle magnet is used to determine the neutral point of start (the ‘home’ point). The power controller has a panel with three manual control switches on it that allow the actuator to either extend, retract, or home the shaft. Once the shaft is ‘homed’ it is ready to run for an irregular type of wave signal.

Data Acquisition

A National Instruments PCI-6014 Data Acquisition Card was used as an interface between the various instruments and the computer used in collecting the data. In total fifteen of the sixteen analog input channels were used. One of the two analog output channels was also used as the interface between the wavemaker program on the PC and the wavemaker.

Load Cells

Load cells were used to measure the tension on the mooring lines that held the models in place during testing. The cells had a maximum tension limit of 5lbs. The objective was to record the loads imparted to the bungee lines by the motion response of the models. Subsequent analysis to determine the maximum and minimum loads would allow a comparison with the available thrust provided by the bow thrusters of the Ro/Ro vessel (in this case the LMSR) to determine if the existing thrusters were capable of providing the required thrust, or whether more capable thrusters would be required.

Wave Probes

Capacitance probes and a sonic wave probe were used to measure the height of the wave in the lee and upstream respectively during tests. Each probe had its own power supply and, once its output signal had been filtered, was connected to the computer via the DAQ Card, allowing the readings to be recorded.

Capacitance Probes

Nine capacitance probes were used to measure the height of the waves on the leeward side of the ITS configuration.

Figure 7 - Capacitance Probes

Sonic wave Probes

A sonic wave probe was used to measure the height of the incident wave upstream of the model.

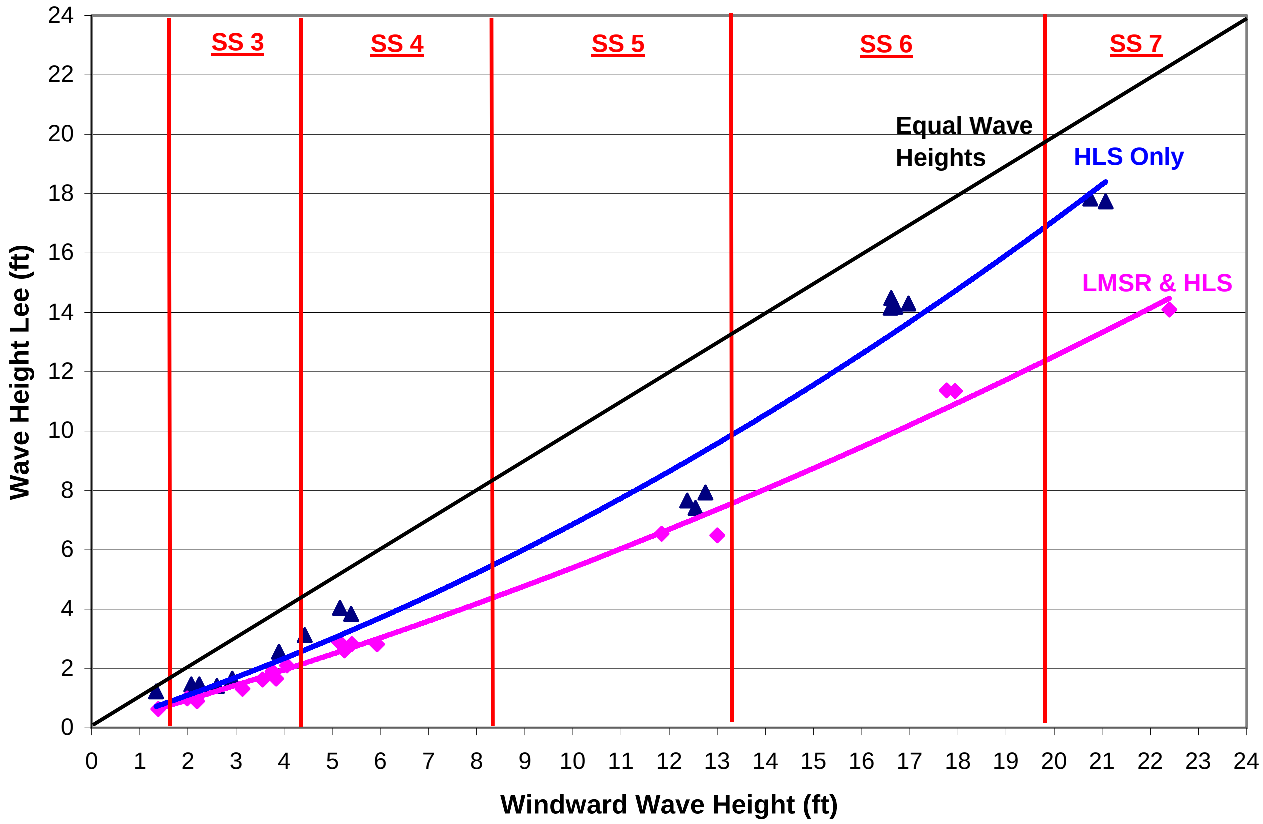

Figure 8 - Lee Wave Height versus Windward Wave Height

Results

Lee Wave Height

The graph illustrates the main results concluded from running the tests. The blue line indicates the reduction in wave height experienced within the lee of the HLS for the HLS moored on its own. The magenta line is an indication of the reduction experienced when both the HLS and the LMSR were moored in the tank as previously described. The black line illustrates where the leeward and upstream wave heights are equal. It is clear that both tests conclusively produced a reduction in wave height of the lee and, as expected, this reduction was greater with the use of both the LMSR and the HLS.

Ramp Torsion

Initially a small circuit was developed which allowed for a light emitting diode to be lit if either corner of the ramp was raised off the deck of the HLS, indicating torsion of the ramp. Unfortunately the system was unreliable, and the idea was abandoned. Simple observation by eye and from video was employed instead. From analysis of the video data collected during the various runs there was no visible torsion effect on the ramp up to sea state 5.

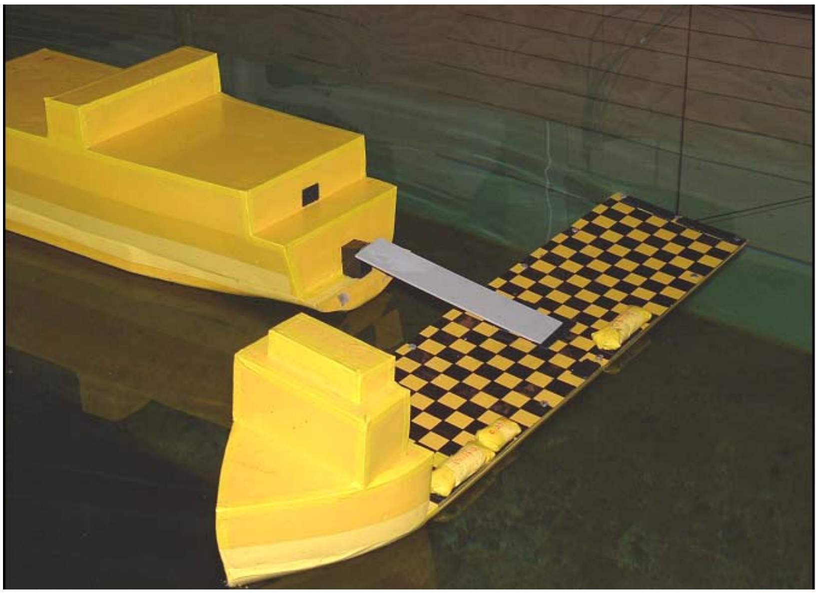

Figure 9 - Ramp Torsion

Deck Wash

From analysis of the high definition video data, it was found that there was no deck wash from the leeward side of the HLS below sea state 5 and there was no windward deck wash visible at any time, up to sea state 7. However, from sea state 5 tests, it was noticeable that the motion of the HLS was causing a scooping action on the leeward side of the ship, producing a small degree of deck wetting.

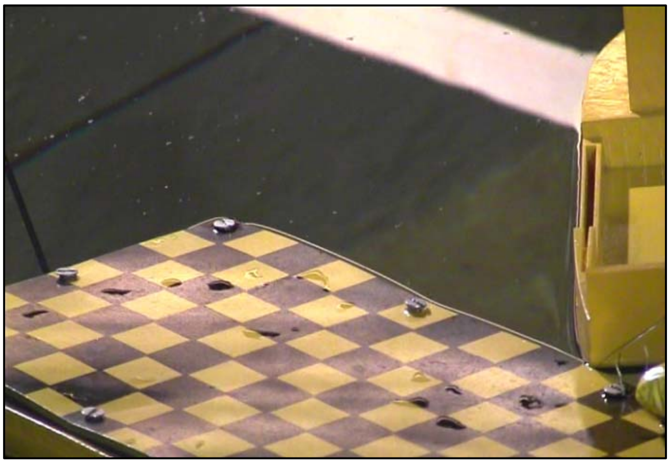

Figure 10 - High Definition Image of the Deck of the HLS

Thruster Forces

The load cell data was collected from five of the six mooring lines. These forces are subsequently scaled up using the Froude scaling method to give an approximate idea of the forces that would be required from the thrusters of a full scale HLS and LMSR to maintain their relative positions. The results are shown below in Figure 11.

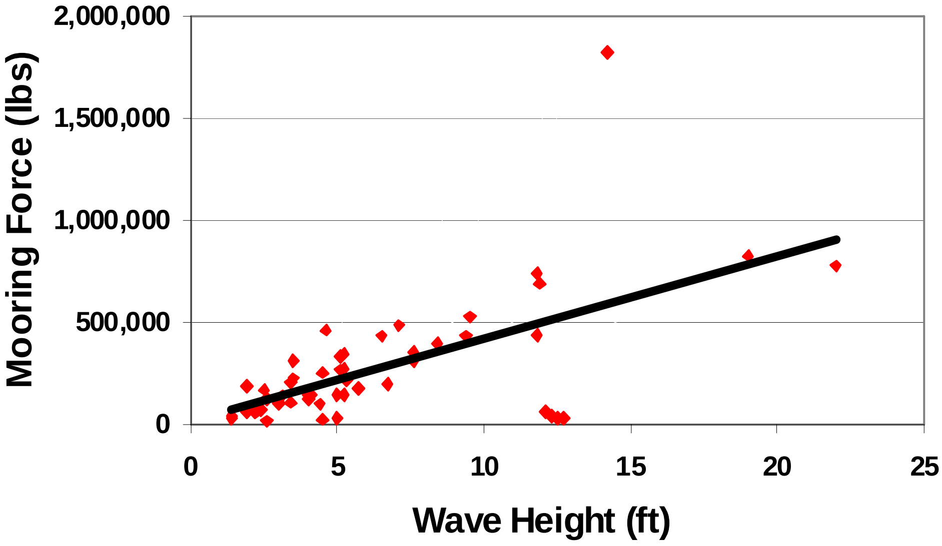

Figure 11 - Mooring Force vs. Wave Height

The results show that, on average, in sea state 4 the average force required by the LMSR thrusters will be 270,000lbs and, in sea state 7, thruster requirements increase to 800,000lbs.

Analysis

Lee Wave Height

Throughout the project, a total of 100 tests were run. The bulk of the testing involved using the basic configuration. From these tests, the Windward Wave Height versus the Lee Wave Height plot (Figure 8) was produced.

The graph clearly indicates the level of reduction that was observed when both the HLS and the LMSR were used, and when it was the HLS only. The best result obtained was during Sea state 3, where the lee wave height saw a reduction of approximately 60%, thus dropping the lee to Sea state 2. As expected, when the sea states increase the level of reduction obtained begins to decrease as the heavy lift ship starts to respond. However, tests run in sea state 7 were still gaining an approximate reduction of 30%. It is obvious that operations would not take place in such conditions but the results indicate that the moorings required for the ITS configuration would be able to remain in place during adverse conditions.

Characterization of the Lee

Figure 12 shows how the significant wave height of the lee varies along the length of the heavy lift ship. The graph shows that the maximum reduction is just forward of amidships while the reduction of the wave height can be seen to be greater at the bow than at the stern.

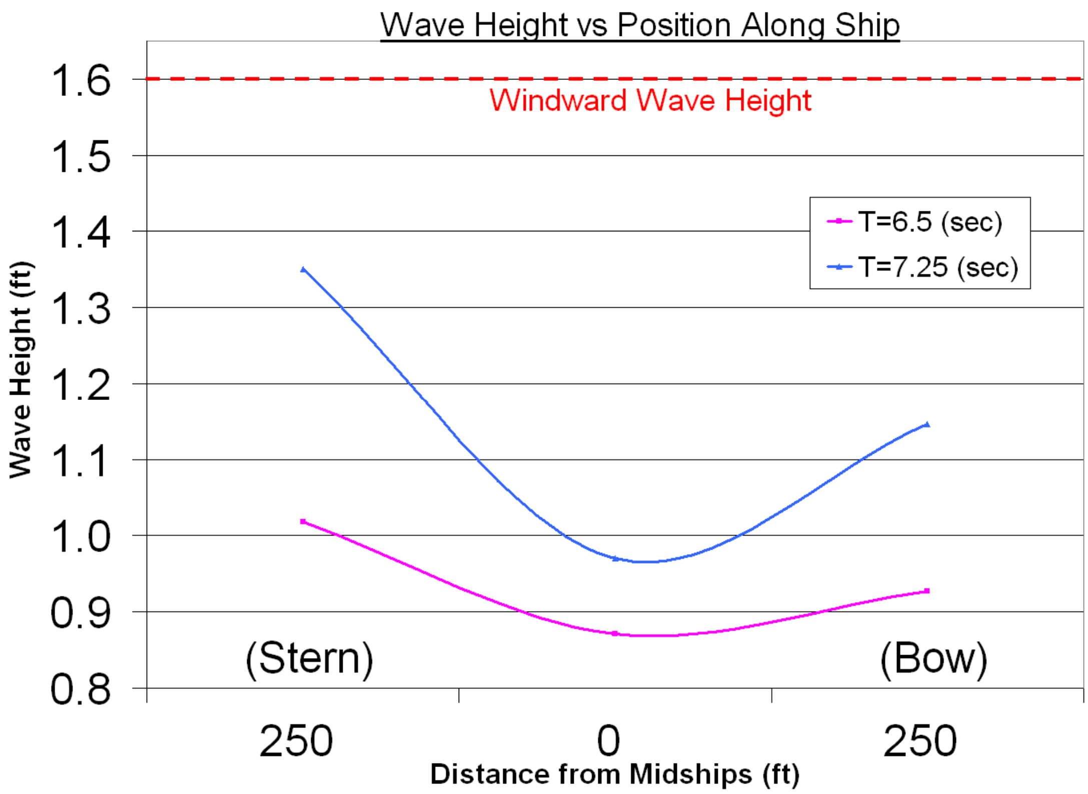

Figure 12 - Characterization of the Lee

Ramp Torsion

As previously mentioned the circuit that was developed didn't perform as intended, and so the system was abandoned. Observation from the video data collected and by the eye during testing found that there was no visible torsion effect on the ramp up to Sea state 5. A more accurate system may need to be employed for further testing, but for this system using the video footage was sufficient.

Deck Wash

During all testing there was no windward deck wash observed on the HLS. At sea state 5 and above, it was observed that the rolling motion of the HLS was causing water to be 'scooped' on to the deck from the leeside of the ship. In sea state 7, approximately 13% of the beam of the ship was wet

Thruster Forces

The results show that the thruster requirements for this configuration of the ITS are huge and far beyond what is expected in full scale. It is likely that these values are inaccurate due to the way the testing was constructed and the equipment used –

- Mooring using bungee chords had essentially created a spring mass system. If the natural frequency of the total system tested was not at least an order of magnitude outside the frequency of the wave (forcing function) then an over excited system may have existed. This system would inherently cause loads on the load cells well outside what would normally occur.
- Froude scaling is an inaccurate way of scaling the data, but was the best option available.

Conclusion

This project and its testing has shown the ITS concept to work and to be very promising for the future. It was observed that, depending on the sea state, the reduction in the wave height on the leeward side of the HLS was between 30-60%. This indicates that transfer operations could be safely carried out in sea state 3, and possibly in limited sea state 4 conditions.

The absence of windward deck wash up to sea state 7 is very encouraging. The level of deck wash experienced from the leeward side of the HLS is to be investigated further. As this occurs in sea state 5 and above and it is unlikely that operations would occur in those conditions, it is not a problematic finding.

Few conclusions can be drawn from the load cell data collected other than to highlight it as a possible area of inaccuracy in the project. It will require more detailed examination than was possible at this level of scale and complexity.

Further Work

The next phase of work will incorporate the use of a larger HLS similar to the Dockwise MV Blue Marlin Heavy Lift Ship. An element of the testing done to date will then be repeated to provide a comparison to the results already obtained. It is expected that the results will be improved, and with the model being larger than previously used, the angle of heel on the HLS will be reduced from 6° to 2° for the same windward freeboard. Whether this affects the level of deck wash observed will be of particular interest.

Figure 13 - MV Blue Marlin

A great deal of interest lies in testing different configurations. There is the ‘T’ construction that this project was modeled on, but also there is the option of having the two ships ‘skin-to-skin’, whereby the two ships are next to each other, both facing the oncoming waves. A second option is having the skin-to-skin arrangement, but with the ships perpendicular to the oncoming waves, with the LMSR on the windward side. There is also scope for investigation into stern-to-stern configurations and bow-to-stern. These will be investigated within the next phase of testing with the larger HLS model scheduled for Nov 04 at NSWCCD.

As previously discussed the thruster force investigation and analysis was inconclusive. The reason for this could be inaccurate equipment, or it could be that the size and level of the testing is too small to obtain an accurate estimate. This needs to be investigated further throughout the next stage of testing to allow for a realistic approximation on the thruster forces required at full scale.

This initial stage of testing has been very much focused on the models and the results obtained within the lee of the HLS. Another area for further work is to look at throughput within a real life scenario allowing for operational effectiveness and operational constraints to be understood and to provide an understanding of how advantageous the system will be at an operational level.

The possibility of running a full-scale test in the summer of 2005 is a realistic one. The option of using an LMSR along with barges in place of a heavy lift ship has been discussed allowing for the ITS configuration to be tested at sea. This could be the first step in performing full-scale tests of the concept, and so work and attention needs to be focused on organizing the required arrangements.

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1. V. Lewis, Editor, “Principles of Naval Architecture,” Volume III Motions in Waves and Controllability, The Society of Naval Architects and Marine Engineers, © 1989
2. www.capitol.northgrum.com/programs/sealift.html